Encrypted File Systems

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CSE 506

Goals

- Protect confidentiality of data at rest (i.e., on disk)
  - Even if the media is lost or stolen
  - Protecting confidentiality of in-memory data **much** harder
- Continue using file system features without losing confidentiality
  - Example: Backup
- Low overheads (space and CPU)
- Change keys and perhaps different keys for different data

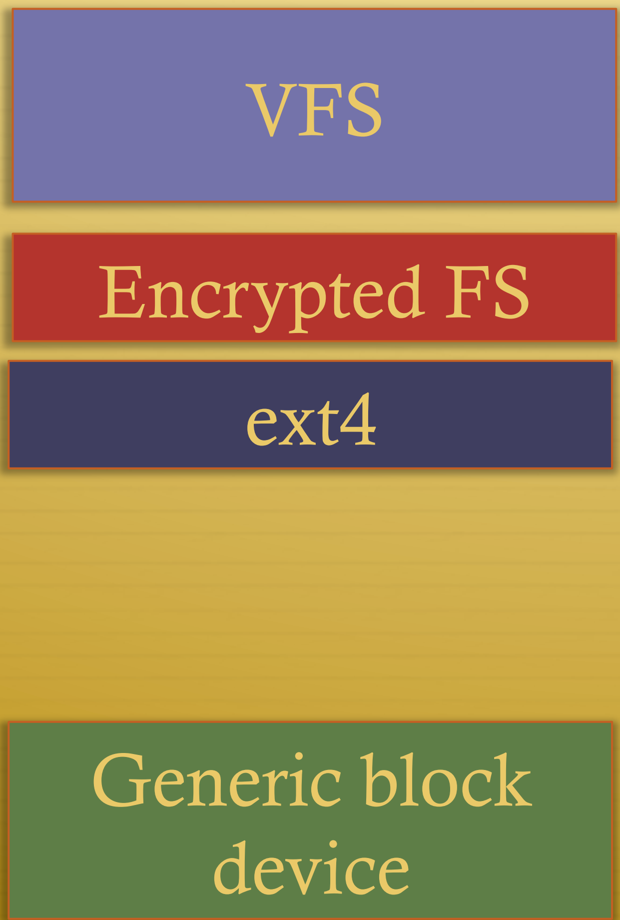
Two major approaches

- Block device encryption
- Transparently encrypt entire partition/disk below the file system
- Linux: dm-crypt
- Windows: BitLocker
- Mac: FileVault 2

Block encryption intuition

- File system is created on a virtual block device
- Low-level read of virtual block device:
  - FS requests a block be read into page cache page X
  - Map to block(s) on real device
  - Request that blocks be read into a temporary page Y
  - Decrypt page X into page X
  - Return to file system
- Similarly, writes encrypt pages before sending to disk

Two major approaches



- File System encryption
- Encrypt data between VFS/Buffer cache and low-level file system
- Linux: eCryptFS
- Windows: EFS
- Mac: FileVault 1

File-based intuition

- Idea: Mount a layered file system over a real one
- Application writes encrypted file 'foo'
- Encrypted FS opens real file foo
  - Stores some crypto metadata (like the cipher used) at the front
  - Encrypts pages in page cache, transparently writes at an offset

File-based intuition

- Read of file ‘bar’
  - Encrypted FS asks real FS for file ‘bar’
  - Uses metadata + secret key to decrypt
  - Stores decrypted pages in page cache
- Challenges:
  - Managing private keys
  - Enforcing read protection on decrypted data in page cache

Pros/Cons of disk encryption

- Pros:
  - Hides directory structure, used space, etc
    - Metadata matters!
  - Can put any file system on top of it
- Cons:
  - Everything encrypted with one key
    - Encryption provides no confidentiality between users on a shared system
  - Data must be re-encrypted before send on network
  - Encryption overhead for public data (like /etc/hostname)

Vs. FS encryption

- Pros:
  - Per-user (or per directory or file) encryption
  - Only encrypt truly secret data
  - Possibly send an encrypted file across network; use key (sent separately!) to decrypt on remote host
- Cons:
  - Harder to hide/obfuscate directory structure and metadata
  - More keys to manage
  - Possibly easier to steal keys (debatable---harder to use TPMs)

Challenges

- Key management
- Read protection of live data
  - Swapping
- Booting the OS

Key management

- Or, where do we keep the secret key?
- Not in the file system!
  - There is a bootstrapping problem here
- Ideas?

Trusted Platform Module

- New hardware extension – common on PCs in last few years
  - Either on motherboard or in CPU chip itself
- Provides two useful features:
- **Measured Execution**: Basically, checks that the booted code (BIOS, bootloader, OS) match a given hash
  - Useful to detect tampering with your software
- **Sealed Storage:** Store a very small amount of data in non-volatile memory in the TPM chip
  - Only accessible from code with hash that wrote it

TPM Idea

- Store the private key for the file system in the TPM's sealed storage
- Only the trusted BIOS/bootloader/OS can access the decryption key
  - The drive alone gets you nothing!
  - Tampering with the OS image (on disk) to dump the disk contents gets you nothing!

Small problem

- Motherboard or CPU dies, taking TPM with it
- How to decrypt your files then?
  - BitLocker: As part of initialization, allow user to print a page with the decryption key. Put this in a safe place (not laptop bag)

Key management in FS-level encryption

- Each user has a key chain of decryption keys
  - Kernel is trusted with these keys
- On-disk, keychain is encrypted with a master key
- Master key is protected with a passphrase
  - That just happens to be the logon credentials
- So, with a user's passphrase, we can decrypt the master key for her home directory, then decrypt the keyring, then the home directory

Challenge 2

- The unencrypted data in the page cache needs to be protected
- If I encrypt my home directory, but make it world readable, any user on the system can still read my home directory!
- Encryption is no substitute for access control!

Swapping

- Care must be taken to prevent swapping of unencrypted data
  - **Or keys!**
  - If part of the file system/key management is in a user daemon, unencrypted keys can be swapped
- One strategy: Swap to an encrypted disk
- Another strategy: Give the encrypted file system hooks to re-encrypt data before it is written out to disk
  - Or put the swap file on the encrypted FS
- Subtle issue

Challenge 3: Booting

- You can't boot an encrypted kernel
- Decryption facilities usually need a booted kernel to work
- Big win for FS encryption: Don't encrypt files needed for boot
- Disk encryption: Usually puts files needed for boot on a separate (unencrypted) partition

Summary

- Two main types of encrypted storage:
  - Block and file system encryption
- Understand pros and cons of each
- Understand key challenges:
  - Key management
  - Swapping
  - Booting